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Dipole Strength Functions in the Actinide Mass Region*

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ABSTRACT: We have calculated a number of neutron- and photon-induced reactions for the actinide nuclei ^{232}Th , ^{238}U , and ^{237}Np . By fitting average resonance capture (ARC) measurements and total neutron capture data, we deduced absolute dipole strength functions for ^{233}Th and ^{239}U . We have found that the M1/E1 ratio is the same as in the ^{176}Lu case, but the total transition strength was larger by about 27%.

1. CALCULATIONS

All calculations were made with our versions of the STAPRE[1] and COMNUC-CASCADE[2] nuclear reaction codes, and the neutron optical potential of Madland and Young[3]. Large sets of modeled, discrete levels were used for the daughter nuclei: ^{233}Th (119 levels), ^{239}U (147 levels). The nuclear level densities were represented by the Gilbert-Cameron formalism, adjusted to agree with the discrete level sets. The neutron strength functions, S_0 and S_1 , and the D_{ob} are shown in Table 1.

We have observed for some time that the parameterization of gamma-ray strength functions is the method of choice for predicting gamma-ray transmission coefficients. For a given multipole type Xl , the two quantities are thus related: $T_{\gamma Xl}(E_\gamma) = 2\pi E_\gamma^{2l+1} f_{Xl}(E_\gamma)$, where the transmission coefficient, $T_{\gamma Xl}$, and in most cases the strength function, f_{Xl} , are functions of the transition energy. We model $f_{E1}(E_\gamma)$ with an energy-dependent Breit-Wigner (EDBW) line shape. The one adjustable parameter available was fixed in a study of ^{176}Lu [5]. We model the M1 strength function to be a constant, in the Weisskopf single-particle approximation, with a value usually extracted from ARC and total neutron capture measurements. The form of the M1 strength function cannot be correct, because it doesn't yield a finite sum rule. However, for ^{176}Lu , because the M1/E1 ratio at energies below 1 MeV and in the energy range 5.2–6.2 MeV are modeled correctly, and the combination of E1 and M1 strength functions produced a correct total radiation width, the absolute values and the functional form for the M1 cannot be too much in error.

Table 1. Some calculated and literature parameter values for ^{233}Th and ^{239}U .

	^{233}Th		^{239}U	
	Computed	Literature[4]	Computed	Literature[4]
$S_0 \times 10^4$	1.22	0.84 ± 0.07	1.08	1.2 ± 0.1
$S_1 \times 10^4$	2.00	1.48 ± 0.07	2.38	1.7 ± 0.3
$D_{\text{ob}}(\text{MeV})$	1.80×10^{-5}	1.68×10^{-5}	1.82×10^{-5}	2.09×10^{-5}
$f_{E1}(\text{MeV}^{-3})$ at $E_\gamma = 5 \text{ MeV}$	1.02×10^{-7}		9.72×10^{-8}	
$f_{M1}(\text{MeV}^{-3})$	2.10×10^{-8}		2.10×10^{-8}	
$\Gamma_{E1}(\text{meV})$	11.4		9.1	
$\Gamma_{M1}(\text{meV})$	14.0		11.3	
$\Gamma_{\text{tot}}(\text{meV})$	25.4	24 ± 2	20.4	23.2 ± 0.3

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2. RESULTS

We tested our E1 systematics for a variety of nuclei from the mass-90 region, through the lanthanide region, and up to tungsten and bismuth[6–8], obtaining good results, using reasonable values for f_{M1} . However, when we examined the ARC measurements[9,10] and total neutron capture data[11,12] for targets ^{232}Th and ^{238}U we found that the ratio $f_{M1}/f_{E1}(E_\gamma)$, for $3.6 < E_\gamma < 4.8$ MeV, was the same as for the lower mass regions, but the total dipole transition strength had to be increased by about 27%. We have applied this increase to all of our subsequent calculations.

Some of our results for target ^{238}U are shown in Fig. 1, compared with Lorentz fits to measurements [13,14]. Our calculations employed an EDBW rather than a Lorentz line shape and are expected to fall below an equivalent Lorentz curve for photon energies less than 11 MeV. In Fig. 2, we show our calculated results for photoabsorption and photoneutron reactions on target ^{237}Np , compared with measurements of Bergere, et al.[15] and Geraldo, et al.[16]. The photoneutron estimation was made using the ratio $\Gamma_n/\Gamma_f = 1.28 \pm 0.15$ from Ref. 16, together with the calculated total photoabsorption cross section.

3. CONCLUSIONS

Based on our studies of targets ^{232}Th , ^{238}U , and ^{237}Np , some of the results of which have been presented here, we now have confidence in modeling dipole strength functions in the actinide region, as we do in the lower mass regions. The reason for the 27% increase in the dipole strength is not known, although possible explanations come to mind (contribution to the sum rule of exchange terms, etc.). We show in Figs. 3 and 4 the absolute E1 and M1 strength functions we have derived as solid rectangles, compared with the experimental values compiled by McCullagh et al.[17]. In the E1 case, we show not the strength function, $f_{E1}(E_\gamma)$, but rather the function $S_{E1} = f_{E1}(E_\gamma)A^{-8/3}E_\gamma^{-2}$; this helps to remove most of its energy and mass dependence. The sizes of the rectangles representing our absolute values are estimates of the error limits of these values. We intend to study other mass regions in the future, in order to expand our understanding of dipole strength functions.

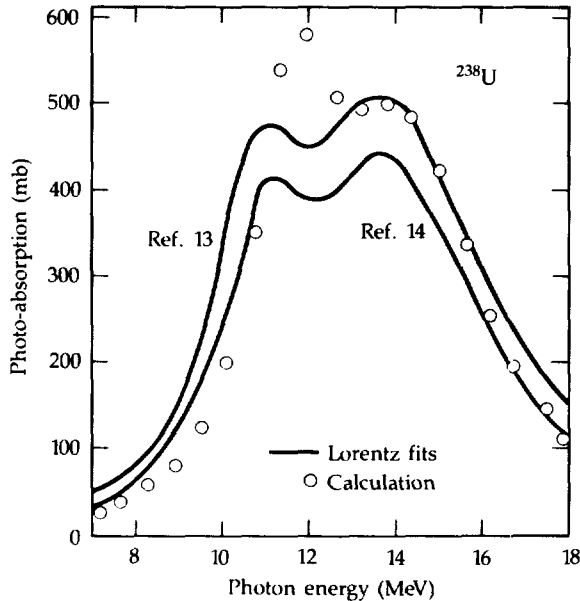


Fig. 1 Calculated photoabsorption cross sections for ^{238}U , compared with Lorentz fits to measurements[13,14]

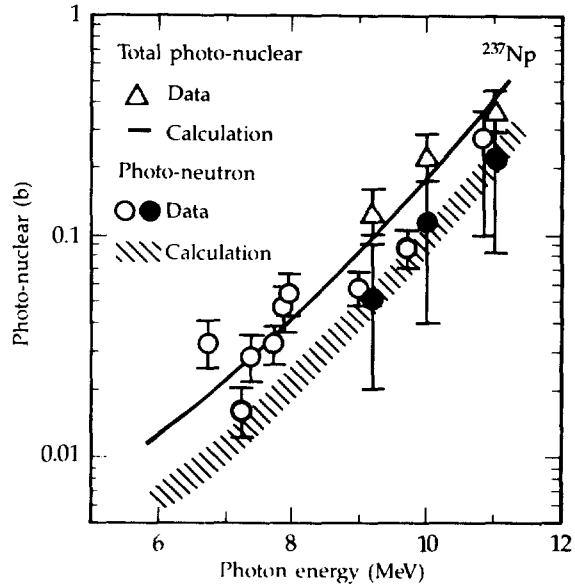


Fig. 2 Calculated and measured[15,16] results for photoabsorption and photoneutron cross sections for target ^{237}Np

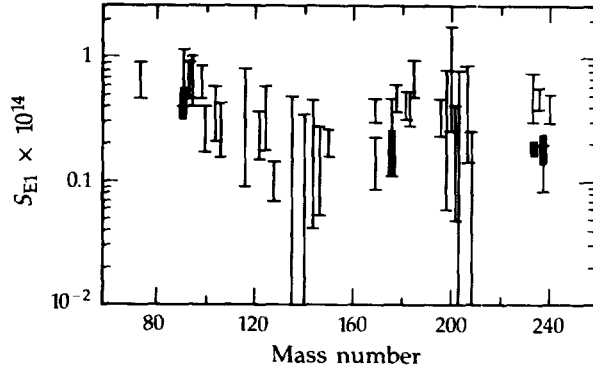


Fig. 3 Absolute E1 strength function values derived in this work (solid rectangles) for ^{233}Th and ^{239}U (for $E_\gamma = 5$ MeV) compared with measured values compiled in Ref. 17; also included are absolute E1 strengths we deduced previously for ^{90}Y , ^{176}Lu [5,6]

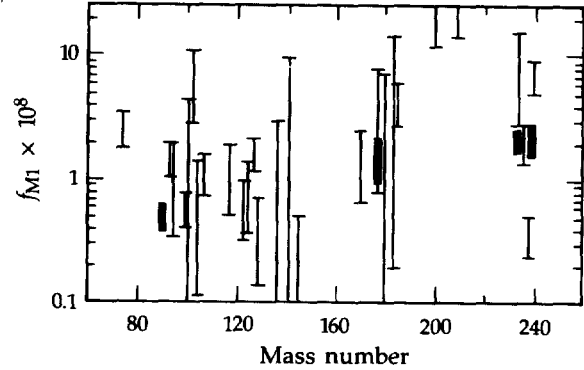


Fig. 4 Absolute M1 strength function values (solid rectangles) we have used in different mass regions, compared with compilation in Ref. 17

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